(19) JAPANESE PATENT OFFICE (JP)

(12) Publication of Unexamined Patent Application (KOKAI) (A)

(11) Japanese Patent Application Kokai Number: **S62-19707**

(43) Kokai Publication Date: January 28, 1987

(51) Int. Cl.[4]	Identification Symbol	JPO File No.
G 01 B 15/02		B-8304-2F
H 01 L 21/66		7168-5F

Request for Examination: Not requested Number of Inventions: 1 (5 pages total)

(54) Title of the Invention: FILM THICKNESS MEASUREMENT METHOD

(21) Application Number: S60-158654

(22) Filing Date: July 17, 1985

(72) Inventor: Koichi Kobayashi
c/o Fujitsu, Ltd.
1015 Kamikodanaka, Nakahara-ku, Kawasaki-shi

(72) Inventor: Kiichi Sakamoto
c/o Fujitsu, Ltd.
1015 Kamikodanaka, Nakahara-ku, Kawasaki-shi

(71) Applicant: Fujitsu, Ltd.
1015 Kamikodanaka, Nakahara-ku, Kawasaki-shi

(74) Agent: Sadakazu Itake, Patent Attorney

SPECIFICATION

1. Title of the Invention

FILM THICKNESS MEASUREMENT METHOD

2. Claims

A film thickness measurement method which is characterized by the fact that an electron beam (15) with a pulse-form electron beam waveform is applied to the surfaces of films (12) that have respectively different thicknesses,

a correlation relationship (Figure 1) is determined in advance by measuring the lag time from the time of application of the current waveform that flows through the films to the [time of the] peak value in accordance with the respective film thicknesses,

when the thickness of a film is to be measured, an electron beam with a rectangular wave[form] is applied to this film, the lag time from the time of application of the current waveform that flows through this film to the [time of the] peak value is determined, and

the thickness of the film is measured by comparing this lag time with the above-mentioned correlation relationship.

3. Detailed Description of the Invention

(Outline)

The present invention is a film thickness measurement method for measuring extremely thin film thicknesses of 1000 Å or less. Furthermore, in this method, in order to measure the film thicknesses of films that are to be measured in a non-contact, non-destructive manner, the measurement of film thicknesses is accomplished by projecting an electron beam with a rectangular wave[form] whose acceleration voltage is varied onto the surface of a formed film, observing the waveform of the electron beam current with a rectangular wave[form] that flows through the film, and comparing [this waveform] with a chart in which the correlation of film thickness, acceleration voltage and waveform is determined beforehand.

(Field of Industrial Utilization)

The present invention relates to a film thickness measurement method, and more particularly relates to a method for measuring the thicknesses of extremely thin films by using an electron beam that has a rectangular wave[form].

As semiconductor devices have become more highly integrated, patterning has become finer as a result of increased density and fineness, and the formation of films with an extremely thin

formed film thickness has also become necessary. Furthermore, a need for the accurate measurement of such film thicknesses has arisen.

Conventionally, in the case of thin films with a thickness of approximately 1000 Å or less, the film thickness is measured by forming a step in thickness in the film that is being measured, projecting light onto this step, and performing measurements by an optical reflection method, or using a method in which the film thickness is measured by utilizing optical interfering light, etc.

However, in such cases, the object of measurement is destroyed; furthermore, such methods are in principle disadvantageous for the measurement of film thicknesses in the microscopic region by optical means, and the drawback of poor precision also arises.

For such reasons, there is a demand for a method that allows accurate measurement of the object of measurement under non-contact, non-destructive conditions even in the case of small film thicknesses in a small area.

(Prior Art)

Figure 5 is a model sectional view of essential parts of a conventional [apparatus] used to measure film thicknesses.

In cases where the object of measurement is made of silicon, etc., that reflects light, it is assumed that the lower-layer object 1 is made of (for example) silicon, and that (for example) a silicon dioxide film is present as a thin film 2 on the surface of this lower-layer object 1. In cases where the film thickness of this silicon dioxide film is measured, the following method is widely used: namely, a step 3 is formed by destroying the thin film 2, and light indicated by the arrow is projected onto this step part using (for example) a thallium light source, etc., with a wavelength of approximately 6000 Å, i.e., a light source which has a wavelength comparable to the film thickness. The reflected light arising from respective differences in the step is caused to draw an image in a display device 4, and the film thickness is measured from this image 5.

As another conventional measurement method, Figure 6 shows a system which is used to measure the film thickness of a light transmitting thin film 7 formed as an upper layer on the lower-layer object 6. In this method, projected light 8 is projected onto the thin film 7 constituting the object of measurement from an inclined direction, and this light passes through the thin film 7 and is reflected from the substrate 6. The thickness of the thin film is determined from the phase difference between this reflected light 9 and the reflected light 10 that is reflected from the surface of the thin film 6 [*sic*][*].

[*] Translator's note: apparent error in the original for "thin film 7."

In the case of such conventional methods, the following drawbacks arise: namely, the reflected light or light refraction from the object of measurement of the light is also associated with the shape of the film thickness measurement region, and is therefore complex, so that the measurement precision is low. Furthermore, in cases where a step is formed in the object of measurement, the object of measurement must be destroyed.

(Problems that the Invention is to Solve)

In the case of film thickness measurement methods using such conventional optical methods, the following problems are encountered: namely, a step is formed by destroying the object of measurement; furthermore, the precision is low due to the complex optical characteristics of the object of measurement, and film thicknesses in regions with a small area cannot be measured, etc.

(Means for Solving the Problems)

The present invention provides a film thickness measurement method which solves the above-mentioned problems. The means used to solve the problems are devised so that an electron beam with a pulse-form electron beam waveform is applied to the surfaces of a plurality of films with different thicknesses, the lag time between the time of application of the current waveform that passes through the film and the [time of the] peak value is measured for films corresponding to the respective film thicknesses, a correlation relationship of the film thickness, acceleration voltage and lag time to the peak [value] of the current waveform is determined in advance, and when the thickness of a formed film is actually measured, an electron beam with a rectangular wave[form] is applied to this film, the lag time from the time of voltage application to the [time of the] peak value is measured from the current waveform that flows through the film, and the film thickness of the film is measured by comparing this measured value with the known correlation relationship.

(Operation)

The present invention utilizes the following fact: namely, when an electron beam that is accelerated by a specified acceleration voltage is projected onto a certain substance, the ultimate depth to which this electron beam penetrates into the substance is related only to the density that is peculiar to this substance and the acceleration voltage of the electron beam. Accordingly, if the ultimate depth reached by the electrons is greater than the film thickness, the current that flows through the film still has the same shape as the waveform of the original rectangular wave (the peak value of the waveform more or less coincides with the rise time). On the other hand, if the ultimate depth reached by the electrons is smaller than the film thickness, the current that

flows through the film has a waveform that differs considerably from the waveform of the original rectangular wave (the rectangular wave has a peak shape, and the peak value lags from the rise time).

Accordingly, if the current waveforms of the rectangular wave that pass through the film are measured in advance for substances with respectively different thicknesses using the acceleration voltage as a parameter, a correlation relationship of the acceleration voltage, lag time to the peak value of the waveform and film thickness is obtained for the [respective] substances.

Utilizing this known correlation relationship, an electron beam with a rectangular wave[form] is projected onto the actual film surface, and the film thickness is measured from the waveform of the current that passes through the film surface.

(Embodiments)

Generally, when an electron beam is projected onto a substance, the electrons reach a certain depth in the substance; in this case, the following universally known equation holds true:

$$R_g = 4.6 \times 10^{-6} E/\rho \qquad (1)$$

In Equation (1),

R_g = depth (cm) reached by electrons inside the substance
ρ = density of the substance (g/cm^3)
E = acceleration voltage (kV) of the electron beam

Accordingly, as the acceleration voltage increases, or as the density decreases, the electrons reach deeper portions of the substance; conversely, as the acceleration voltage decreases, or as the density increases, the electrons can reach only shallower portions of the substance.

Figure 1 is a diagram of the correlation between the time required for the rectangular wave[form] of an electron beam with a rectangular wave[form] passing through a thin film to reach the peak value from the time of application of the rectangular wave, and the acceleration voltage of this electron beam with a rectangular wave[form], in a case where such a thin film is formed from a specified substance, and such an electron beam with a rectangular wave[form] is projected onto this thin film. This correlation is expressed with the thickness of the thin film taken as a parameter.

Figure 2 is a sectional view illustrating the film thickness measurement method that is used in order to determine the above-mentioned relationship diagram.

A thin film comprising (for example) a silicon dioxide film 12 is formed on the surface of a silicon substrate 11, and the substrate is grounded by connection to a synchroscope 14 via a connection terminal 13. An electron beam 15 with a rectangular wave[form] which is accelerated at a specified acceleration voltage is projected onto a surface region of this thin film as indicated by the arrow [in Figure 2].

A beam current with a rectangular wave[form] flows through the silicon substrate 11 and silicon dioxide film 12, and the current waveform is detected by the synchroscope 14; accordingly, the lag time to the peak value can be determined from this waveform.

Figure 3 (a) through Figure 3 (f) respectively compare the electron beam with a rectangular wave[form] that is applied to the thin film, the thickness of the thin film, and the current waveform that passes through the substrate and thin film.

Figure 3 (a) shows the original rectangular wave[form] that is applied to the thin film, and Figures 3 (b) through 3 (f) show the film thicknesses when respective acceleration voltages of 5 kV, 10 kV and 20 kV are applied.

Specifically, the waveform shown in Figure 3 (b) indicates the waveform in the case of a thickness of 5000 Å at an acceleration voltage of 5 kV, a thickness of 15,000 Å at an acceleration voltage of 10 kV, and a thickness of 20,000 Å at an acceleration voltage of 20 kV.

Similarly, the waveform shown in Figure 3 (c) indicates the waveform in the case of a thickness of 4000 Å at an acceleration voltage of 5 kV, a thickness of 12,000 Å at an acceleration voltage of 10 kV, and a thickness of 40,000 Å at an acceleration voltage of 20 kV, the waveform shown in Figure 3 (d) indicates the waveform in the case of a thickness of 2000 Å at an acceleration voltage of 5 kV, a thickness of 6000 Å at an acceleration voltage of 10 kV, and a thickness of 20,000 Å at an acceleration voltage of 20 kV, the waveform shown in Figure 3 (e) indicates the waveform in the case of a thickness of 1000 Å at an acceleration voltage of 5 kV, a thickness of 3000 Å at an acceleration voltage of 10 kV, and a thickness of 10,000 Å at an acceleration voltage of 20 kV, and the waveform shown in Figure 3 (f) indicates the waveform in the case of a thickness of 500 Å at an acceleration voltage of 5 kV, a thickness of 1500 Å at an acceleration voltage of 10 kV, and a thickness of 5000 Å at an acceleration voltage of 20 kV.

Specifically, the waveform shown in Figure 3 (b) [*sic*] is a diagram of the current waveform that passes through the thin film and substrate, as measured by the synchroscope. As the acceleration voltage increases, or as the film thickness decreases, the diagram of the current waveform that passes through the thin film and substrate approaches the diagram of the original current waveform.

Accordingly, the film thickness can be measured by using the peak value (indicated by P in the figures) of the current waveform as a reference, and measuring the lag time of this value from the time of application of the original rectangular wave.

This lag time ranges from approximately n sec to m sec depending on the acceleration voltage.

Figure 4 is a model sectional view which illustrates a thin film measurement method constituting an embodiment of the present invention.

Here, it is assumed that a silicon dioxide film 22 is present on the surface of a silicon substrate 21, that a recessed part 23 with a diameter of a few microns is formed [in this silicon dioxide film 22], and that the thickness of a thin film 24 in this area is measured.

In this measurement method, the film thickness can easily be measured by constricting the beam spot of an electron beam 25 (which has a rectangular wave[form]) indicated by the arrow to match the dimensions of the thin film 24 located in the recessed part, projecting this beam onto the thin film, measuring the current waveform that is imaged by a synchroscope 26, measuring the lag of the peak value, and referring to the predetermined correlation diagram illustrated in Figure 1.

(Effect of the Invention)

Thus, as was described above in detail, the film thickness measurement method of the present invention makes it possible to measure the thicknesses of extremely thin films, and possesses great merit in that high-precision semiconductor devices with highly integrated circuits can be provided by accurate measurement of such film thicknesses.

4. Brief Description of the Drawings

Figure 1 is a correlation diagram of the time to the peak value of the rectangular wave and the acceleration voltage of the electron beam, with the film thickness used as a parameter.

Figure 2 is a model sectional view of essential parts used to illustrate the film thickness measurement method of the present invention.

Figures 3 (a) through 3 (f) are current waveform diagrams.

Figure 4 is a model sectional view which illustrates a thin film measurement method constituting an embodiment of the present invention.

Figure 5 is a model sectional view of essential parts illustrating a conventional [device used to] measure film thicknesses.

Figure 6 is a model sectional view of essential parts illustrating another conventional [device used to] measure film thicknesses.

In the figures, 11 indicates a silicon substrate, 12 indicates a silicon dioxide film, 13 indicates a connection terminal, 14 indicates a synchroscope, 15 indicates an electron beam with a rectangular wave[form], 21 indicates a silicon substrate, 22 indicates a silicon dioxide film, 23 indicates a recessed part, 24 indicates a thin film, 25 indicates an electron beam, and 26 indicates a synchroscope.

Agent: Sadakazu Itake, Patent Attorney [*seal*]

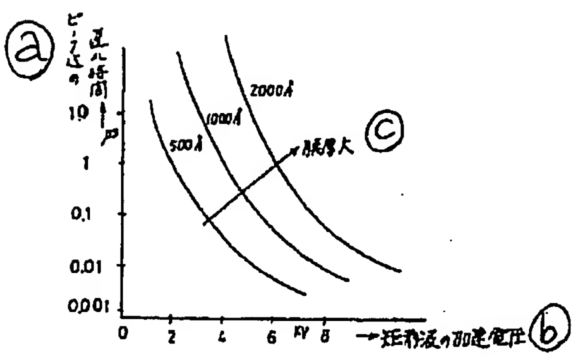

Figure 1
Correlation diagram of acceleration voltage of rectangular wave and lag time to peak

a: Lag time to peak (microseconds)
b: Acceleration voltage of rectangular wave
c: Increasing film thickness

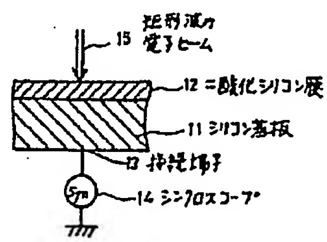

Figure 2
Sectional view illustrating thin film measurement method

11: Silicon substrate
12: Silicon dioxide film
13: Connection terminal
14: Synchroscope
15: Electron beam with rectangular wave[form]

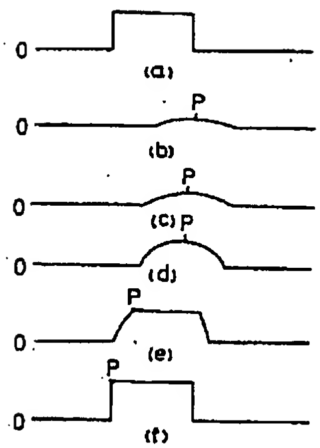

Figure 3
Current waveform diagrams

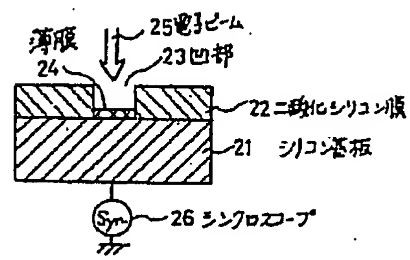

Figure 4
Sectional view
illustrating thin film measurement method of the present invention

21: Silicon substrate
22: Silicon dioxide film
23: Recessed part
24: Thin film
25: Electron beam
26: Synchroscope

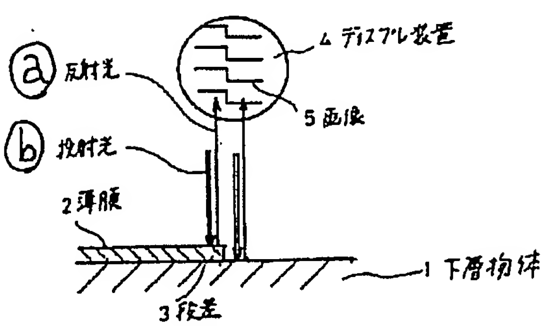

Figure 5
Sectional view
showing [operating] principle of a conventional film thickness measurement method

1: Lower-layer object
2: Thin film
3: Step
4: Display device
5: Image
a: Reflected light
b: Projected light

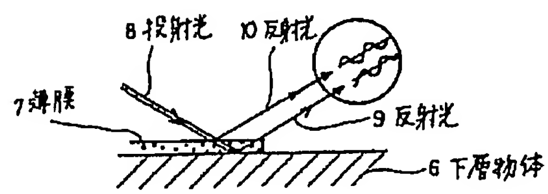

Figure 6
Sectional view
showing [operating] principle of a conventional film thickness measurement method

6: Lower-layer object
7: Thin film
8: Projected light
9: Reflected light
10: Reflected light